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DEMONSTRATION OF THE METHOD OF LEAST WORK.

BY WM. CAIN, C. E.; M. AM. SOC. C. E.

1. A new method of ascertaining the stresses in elastic structures by means of the principle of "Least Work" has been elaborated by Castigliano, in his "Théorie de l'Equilibre des Systémes Élastiques" (Turin, 1879), who claims to have given the first complete demonstration of the theorem of least work, though several authors have touched upon it from 1818 to the present time.

In the "Transactions of the American Society of Civil Engineers" for April, 1891, the writer published an article entitled "Determination of the Stresses in Elastic Systems by the Method of Least Work," in which two new and complete demonstrations of the principle of least work are given, both being founded on the well-known principle of "virtual velocities" of mechanics "applied to framed structures."

The following article is an abstract of the briefer demonstration, given in the article by the writer before mentioned, and is based on "the theory of deflections," which will first be given. A few preliminary articles on "elastic work" of a bar in tension or compression, "superfluous"

bars in trusses, etc., are added to make the paper sufficiently complete in itself; especially as the aim is to make the demonstrations as simple and elementary as possible.

2. If we call a the length of a prismatic bar, w its cross section, e its modulus of elasticity and k its change of length under the stress s, then, by the fundamental law of elasticity, when the resultant stress s acts along the axis and the limit of elasticity has not been exceeded, we have,

$$k = \frac{a\,s}{e\,w} = c\,s \ldots\ldots (1),$$

if for brevity, we put, $c = \frac{a}{e\,w}$.

If the bar lengthens or shortens the amount k by the action of a load P, acting in the direction of its axis, which *gradually* increases from o to its greatest value P, the stress likewise increases from o to its greatest value s, and at any instant the stress is exactly equal to the load. If in any small interval of time the average stress is s, whilst the length changes an amount $d\,k$, due to a slight increment of load, the work done is s. d k; therefore as the load changes from o to P, the total work done is the limit of the sum,

$$\Sigma\,(s.\ d\,k) = \Sigma\left(\frac{k.\ d\,k}{c}\right),$$

between the extreme values k = o and k = k, corresponding to s = o, and s = s.

∴ *The total work of deformation* for a *gradually applied* load is,

$$\frac{1}{c}\int_0^k k\,d\,k = \frac{1}{c}\,\frac{k^2}{2} = \frac{1}{2}\,c\,s^2 = \frac{1}{2}\,s\,k \ldots\ldots (2);$$

or since load P = s, *work* = ½ *load* × *change of length.*

For a *suddenly applied* load P, causing a change of length k^1 and maximum stress s, the work of the load is $P\,k^1$, and since the stress *gradually* increases from o to s, the work of deformation, by (2), is $\frac{1}{2}\,s\,k^1$, and since these are equal $s = 2\,P$, or the *maximum* stress is double the load; hence by (1) the change of length is double that for a gradually applied load. After a series of oscillations this change ultimately becomes that due to a gradually applied load and s reduces to P. As, in what follows, we are only concerned with the ultimate or statical stress, we shall always compute *the work of deformation* of a bar, as for a *gradually applied* load, by the formula (2),

$$\frac{1}{2}\,c\,s^2 = \frac{1}{2}\,\frac{a}{e\,w}\,s^2 \ldots . \quad (3).$$

3. *Superfluous bars.* When the figure of a truss has more lines than are strictly necessary to define its form; *i. e.*, to fix its apices when the length of sides are given in order, the extra sides are said to be "*superfluous.*"

The relation between the least number of sides m, or the number of "necessary" bars in a truss and the number of joints or apices n, for *strictly* defining the form of a figure of invariable form, is easily arrived at.

Thus for plane figures (which we shall alone consider in this article) assume the position of one side, thus fixing the two apices at its ends. From these apices we can fix another with two new sides, then another with two new sides from two apices previously fixed, and so on; therefore to each of the (n—2) joints other than the first two corresponds two sides, so that the total number of necessary sides $m = 2\,(n-2) + 1 = 2\,n-3$. If the number of sides exceeds $(2\,n-3)$, the extra number are "superfluous" to strictly define the form. A less number will give a figure that can change its shape without changing the lengths of its sides.

It is well known that the laws of statics alone suffice to determine the stresses in any truss, whose pieces are free to move at the joints, when the number of bars is just that necessary to strictly determine the form. When there are superfluous bars or continuous members without free play at the joints, the theory of elasticity must be used to give the additional equations, which, added to those furnished by the ordinary laws of statics alone, give as many equations as unknown stresses, from which the latter are obtained by elimination. The theory of "least work" offers a direct solution of such problems.

It may be observed, if a truss is subjected to such *conditions*, that more than two joints are fixed in position, that there may be more bars than are strictly necessary to define the form, even when $m = 2n-3$. It is always easy in such cases to ascertain the number of "superfluous bars" by supposing the truss built out from two joints taken as fixed, apex by apex, towards the other fixed joints.

The number of bars just sufficient to fix the position of each apex, other than the fixed ones, is easily seen; all other bars are superfluous to this end and must be so treated when applying the method of least work.

4. *Derivative of the Work of Deformation with respect to an external force. Deflection.* Consider a truss of invariable form, without superfluous bars, and let a force unity act in the direction of and along the line of action of any external force P. Then when all the original external forces, such as P, are removed and we have only the force unity acting on the truss, with the corresponding reactions, if any, call u the stress in any bar due to the force unity in question. Also call the length of this bar a, its cross section w and modulus e, and let us conceive it as elongating an amount $\triangle l = \frac{a s}{e w}$, or the exact amount

caused by the stress s due to all the external forces such as P (the force unity being omitted), and that this elongation alone causes the displacement $\triangle p^1$ of force unity in the direction of that force. In applying the principle of virtual velocities we have the right to suppose any displacement $\triangle 1$ we choose, and for convenience we take that the bar actually sustains when the truss is fully loaded and not what it would sustain from the force unity.

Now assuming u to be tension, the displacements of the ends of the bar are in the opposite directions to the forces acting, so that the virtual velocity is negative. We shall assume the displacement $\triangle p^1$ to be in the direction of the force unity until otherwise ascertained.

We have now by the principle of virtual velocities,

$$1. \quad \triangle p^1 - u. \triangle 1 = 0;$$

$$\therefore \triangle p^1 = u \frac{a\,s}{e\,w}.$$

If u or s are compressive, it is evident that they must have the minus sign in the above equation. Should $\triangle p^1$ thus become minus in any case, the displacement will be contrary to the direction of the supposed force unity.

Continuing thus to find the displacement of force 1, due to the change of length of each bar in turn, the other bars remaining unchanged, we have for the total displacement of the force unity, acting in the direction of external force P, the formula,

$$\triangle p = \Sigma\left(u \frac{a\,s}{e\,w}\right) \ldots . \quad (4),$$

the sum extending to all the bars of the truss.

But since this displacement is that caused by the actual stresses in all the bars due to the original external forces, it must equal the actual displacement of force P along its direction or the deflection of the truss in the direction of force P.

This is a known formula, by means of which the *deflection* of any truss containing only "necessary" bars in the direction of any given external force or supposed force, can be computed. In using it, strict attention must be paid to the signs of u and s, plus for tension, minus for compression.

We shall now put this formula in a different shape and from it eventually deduce the theory of least work.

If we call X the stress (+ for tension, — for compression) in any bar due to all the loads and their corresponding reactions, when P is omitted, we have the stress in any bar,

$$s = X + u\,P;$$

whence, taking the derivative, since X is entirely independent of P,

$$\frac{d\,s}{d\,P} = u.$$

$$\therefore \triangle p = \Sigma\left(\frac{a\,s}{e\,w}\cdot\frac{d\,s}{d\,P}\right) = \frac{d}{d\,P}\,\frac{1}{2}\,\Sigma\left(\frac{a\,s^2}{e\,w}\right) \quad . \quad . \quad . \quad (5),$$

in which it is understood that s must be replaced by $X + u\,P$. Now by eq. (3), $\frac{1}{2}\,\frac{a\,s^2}{e\,w}$ represents the elastic work of one bar, so that in words (5) shows that *if we express the work of deformation of the bars as a function of the external forces, its derivative with respect to one of the forces gives the displacement, in the direction of the force, of its point of application.*

This is called by Castigliano "the principle of the derivative of work," or it may be termed the theorem of deflection. If we call the work of deformation of the system, F, it is plain, from the above that when $\frac{d\,F}{d\,P} = \Delta p$ is

plus, the displacement is in the direction of the force; when minus, in a contrary direction. When two equal forces, directed both toward or both from each other, along the same line (as in the case of the horizontal thrusts of an arch hinged at the abutments), are designated by the same letter P, if we call P and P^1 the two forces and F the work of deformation of the truss, then $\frac{dF}{dP}$ and $\frac{dF}{dP^1}$ give the actual displacements of P and P^1, along the directions of the forces; both minus or both plus, according as the motion is opposed to the direction of the force or with it; so that $\frac{dF}{dP} + \frac{dF}{dP^1}$ gives the total relative displacements of P and P^1. In case we can regard the apex, at which either force as P^1 acts, as fixed, then $\frac{dF}{dP}$ represents, as usual, the displacement of one apex with respect to the other.

If a truss has *superfluous* members, we can suppose them removed and that two opposed forces act at either end of each bar, each equal to the final stress in the member and acting in the same direction. Then if we designate by P and P^1, the forces replacing the action of any one bar, at either end, upon the apices, then if F represents the work of the necessary bars, $\frac{d\ F}{d\ P} + \frac{d\ F}{d\ P^1}$ gives the total relative displacement of the apices. Now as we can regard $P^1 = P$ as a function of P, the total derivative of F with respect to P is $\frac{dF}{dP} + \frac{dF}{dP^1}\frac{dP^1}{dP}$; but since $P = P^1$, $\frac{dP^1}{dP} = 1$, therefore *the total derivative of F with respect to P* is equal to

$$\frac{dF}{dP} + \frac{dF}{dP^1};$$

which, from what precedes, is equal to the total relative displacement of the apices, where P and P^1 are applied. Hence, in any case, to find the relative displacement of two apices, between which two equal and opposed forces, P and P^1, act, we have only to take the total derivative of F with respect to one of the forces P, so that it is not necessary to designate the two opposed forces by different letters.

5. Demonstration of the Theorem of Least Work.

Let us suppose that we have a truss of any kind, with superfluous bars numbered n, $n + 1, \ldots$, whilst the $(n-1)$ necessary bars (system N) are numbered consecutively, $1, 2, \ldots, (n-1)$.

Let,

$X_1, X_2, \ldots X_{n-1}$ = stresses in bars $1, 2, \ldots, (n-1)$ of a frame supposed to consist of necessary bars alone (system N) subjected to the actual loading.

$u_1, u_2, \ldots u_{n-1}$ = stresses in bars $1, 2, \ldots, (n-1)$ of system N alone, by forces unity acting towards each other from either end of the original position of superfluous bar n, all the superfluous bars being removed.

$v_1, v_2, \ldots v_{n-1}$ = stresses in bars $1, 2, \ldots, (n-1)$ of system N alone, caused by forces unity acting towards each other from the apices of superfluous bar $(n + 1)$, all the superfluous bars being removed.

Similarly we proceed for other superfluous bars, if any. The stresses X, u, v, . . . , can all be found by the laws of statics alone. Now designating the length, cross section and modulus of elasticity of any bar, by a, w and e, respectively, with the same subscript as the number of the bar, we have the total elastic work of deformation of all the bars, including the superfluous bars, expressed by

$$G = \tfrac{1}{2} \Sigma \left(\frac{a\, s^2}{e\, w} \right) + \tfrac{1}{2} \frac{a_n s_n{}^2}{e_n w_n} + \tfrac{1}{2} \frac{a_{n+1} s_{n+1}{}^2}{e_{n+1} w_{n+1}} + \ldots,$$

in which the sum Σ' extends to the necessary bars alone, or bars 1, 2, . . . (n—1). In this expression it is understood that for *s*, the actual stress in any bar, we must substitute expressions of the type,

$$s = X + u\, s_n + v\, s_{n+1} + \ldots,$$

on supplying the proper subscripts pertaining to the bar considered.

The last expression follows at once from the principle of "superposition of effects."

On designating by F the elastic work of the necessary bars alone, we have

$$F = \tfrac{1}{2}\, \Sigma' \left(\frac{a\, s^2}{e\, w} \right);$$

the sum including only the necessary bars and *s* being expressed as a function of s_n, s_{n+1}, . . , as above.

We shall next regard the superfluous bars n, n + 1, . . . , as temporarily removed and replace their action by two forces for each bar, each equal to the stress in the superfluous bar and acting towards each other, as all bars are assumed to be in tension until otherwise determined.

It has been shown above that treating these forces, s_n, s_{n+1}, . . . , as external forces and *independent of each other*, that $-\frac{d\,F}{d\,s_n}$ represents the increase in distance between the apices at the extremities of bar *n*, the minus sign being used, since the two forces s_n, s_n, replacing the tension of the bar upon the joints at its ends, act in the opposite direction to the displacements. Similarly for the other deflections. Again, since s_n is supposed to equal the actual stress in bar *n* in the complete structure under the loading, it follows that $-\frac{d\,F}{d\,s_n}$ must equal the elongation of the bar *n* under the stress s_n when all the superfluous bars are in place, since the real change of length of any superfluous

bar n is a necessary consequence of the real changes of length of the necessary bars alone, and it can be found as above, without knowing the changes of length of the superfluous bars beforehand. The increase in distance between the apices at the extremities of superfluous bar n, as determined from "system N," must therefore exactly equal the elongation of bar n under the stress s_n when in place.

$$\therefore -\frac{d\,F}{d\,s_n} = \frac{a_n\,s_n}{e_n\,w_n}$$

or,
$$\frac{d\,F}{d\,s_n} + \frac{a_n\,s_n}{e_n\,w_n} = 0 \ldots\ldots\ldots (6).$$

A similar expression obtains for each of the superfluous bars, so that we always have as many equations as there are superfluous bars.

Now each equation of the type above (6), can be found by taking the partial derivatives of the expression for G above, successively with respect to s_n, s_{n+1}, . . . , *treated as independent of each other*, and placing the results separately equal to zero, so that the equations needed will be of the type,

$$\frac{d\,G}{d\,s_n} = 0, \quad \frac{d\,G}{d\,s_{n+1}} = 0, \ldots\ldots\ldots (7).$$

From these equations we find, by elimination, s_n, s_{n+1}, . . . , and then substituting these values in equations of the form,

$$s = X + u\,s_n + v\,s_{n+1} + \ldots,$$

we find all the stresses, s_1, s_2, . . . s_{n-1}.

Theorem of Least Work. Therefore, *to determine the unknown stresses, we express the work of deformation of the whole system as a function of the stresses in the bars taken as superfluous, then treating these stresses as independent in the differentiation, we express that the work of*

the necessary bars and one superfluous bar at a time be a minimum; or preferably, that the work of all the bars be a minimum, provided we assume the fiction, that the stresses of the superfluous bars are entirely independent of each other.

It is this which constitutes the method of "least work."

When there is but one superfluous bar, the true stresses correspond exactly to a minimum of elastic work, but for a greater number of superfluous bars this is not necessarily true, since the stresses in the superfluous bars are functions of each other and not independent, as we assume in forming eqs. (7). This consideration has not been pointed out by any previous author, as far as the writer knows.

The theorems of "deflection" and "least work" have now both been proved by aid of the method of virtual velocities, which, it is seen, is especially adapted to the object in view, as it leads easily and unmistakably to the theorems, and leaves, no doubt, whatsoever as to the exact interpretation of results.

The theorems are easily extended to solid beams, composed of molecules, resisting any change of distance apart by forces varying directly as the changes of distance, according to the law of elasticity first assumed; for such bodies can be treated, therefore, as articulated systems, whence the above theorems directly apply, the unknown stresses between certain molecules taking the place of the stresses in the superfluous bars of the preceding demonstrations. The theorems are therefore perfectly general and apply to solid beams, articulated structures, or combinations of the two, including structures having certain members continuous over certain apices; but it would take us too far in this article to give the most convenient methods of dealing with such composite structures, which may be found, however, partly in the article by the writer in the April, 1891, Transactions Am. Soc. C. E., and very fully in Castigliano's very exhaustive treatise before mentioned.

ADDITIONS TO THE AVIFAUNA OF NORTH CAROLINA SINCE THE PUBLICATION OF PROF. ATKINSON'S CATALOGUE.

BY J. W. P. SMITHWICK.

1. *Alca torda.* Razor-billed auk. The head, wing and foot of one of this species were sent to the Department of Agriculture, Washington, D. C., for identification by Lieut. Foley, U. S. N. It was taken at Lookout Cove on February 15, 1890. Others were seen. (Auk, April, 1890).

2. *Branta leucopsis.* Barnacle Goose. "Has been taken in North Carolina." (Bul. Am. Mus. Nat. His., Vol. I, No. 7, July, 1886; Allen in "Birds of Massachusetts").

3. *Porzana jamaicensis.* Black Rail. Rare summer visitor in the middle and western sections. Found breeding in both places.

4. *Columbigallina passerina.* Ground Dove. Accidental summer visitor in the mountain region. So far two specimens have been seen and identified. (Cairns).

5. *Archibuteo lagopus sancti-johannis.* American Rough-legged Hawk. Seen occasionally in the winter and spring in the west. (Cairns).

6. *Strix pratincola.* American Barn Owl. One taken at Newport, N. C., by James Moore, Esq., November 7, 1889, and sent to Brimley to mount.

7. *Empidonax flaviventris.* Yellow-bellied Flycatcher. Rare transient in the middle section; one was taken August 11, 1890, in the mountains.

8. *Empidonax pusillus traillii.* Fraill's Flycatcher. One was taken in the mountain region in September, 1889. (Cairns).

9. *Otocoris alpestris praticola.* Prairie Horned Lark. Rare winter visitor in the middle and western sections.

10. *Quisculus quiscula æneus.* Bronzed Grackle. Tolerably common transient in the mountains. (Cairns).

11. *Ammodramus henslowii.* Henslow's Sparrow. One female taken in April, 1890, in the western section. (Cairns).

12. *Ammodramus maritimus.* Seaside Sparrow. One taken by myself, May 15, 1891, in a marsh near Plymouth, N. C. No others were seen.

13. *Chondestes grammacus.* Lark Sparrow. Rare summer visitor at Raleigh. Breeds. (Brimley).

14. *Clivicola riparia.* Bank Swallow. Rare transient in the middle and mountain sections.

15. *Helminthophila bachmani.* Bachman's Warbler. Probably a rare summer visitor. One taken at Raleigh, April 27, 1891. (Brimley).

16. *Helminthophila leucobronchialis.* Brewster's Warbler. Rare transient at Raleigh, N. C. (Brimley).

17. *Dendroica palmarum hypochrysea.* Yellow Palm Warbler. Tolerably common transient at Raleigh, N. C. (Brimley).

18. *Turdus aliciæ.* Gray-cheeked Thrush. Transient visitor, rare at Raleigh; tolerably common in the west.

SANS SOUCI, N. C.

THE ALEXANDER COUNTY METEORIC IRON.

BY S. C. H. BAILEY.

About the year 1875, General T. L. Clingman, of Asheville, presented me with a small piece of meteoric iron, concerning which he was able to give me little information further than that it had been found some years before in

Alexander county, and had been given to him by a Mr. Andrews. The piece was evidently a fragment that had been broken from a larger mass, was rather smoothly rounded upon its broadest surface, and, though wholly devoid of a proper crust, the exterior was quite protected from further oxidation upon that side by the alteration produced from weathering. It did not in any part show any evidence of the pittings common to all classes of meteorites. Its structure is coarsely granular, or made up of polygonal fragments, lightly adherent, with intervening thin folias of Schreibersite and cracks or veins of iron oxide, cementing the mass together. In some instances the Schreibersite also forms small blocks, with rounded outlines. The limited area of the surface cut is only sufficient to show that it belongs to the Braunite type of Meunier, or the "Grobe Lamellen of Brezina." It has a density of 7.635 and its composition, as shown by Venable, is

Iron	91.70
Nickel	5.86
Cobalt	.63
Phosphorus	.095
Oxygen and loss	1.72
	100.00

Where the iron is free from the Schreibersite it cuts easily, takes a good polish, is very light in color, and upon etching it shows neither the Newmann lines nor the figures of Widmanstädt, but it quickly blackens upon applying the acid, and is very slowly corroded. In grains it is quite malleable, but rather brittle in mass. It is most probable that the fragment in my possession came from near the surface of the main mass, and it may present different conditions from the interior portions, which have been protected from the action of the soil or atmosphere. From comparison with examples of the other North Carolina meteoric irons, it is seen to differ essentially from all of

them, the only one which it at all resembles being that from "Duel Hill," found in 1873, but several marked differences are apparent upon direct comparison. While the Alexander county was found some years prior to that from Madison county, the places of find are widely apart, and the densities and analyses do not nearly approximate. This iron does not seem to be especially prone to oxidation, and while it belongs to a class that is not very compact in structure, yet the condition of a part of the surface of this specimen above mentioned would indicate that even when denuded of its natural crust its exterior (unless exposed in a very damp soil) would form a new protective coating of oxide which might preserve the parent mass for many years.

Unless it has been so destroyed, the original mass must still be in existence, and as has been the case with other meteorites found in that State, it may now be lying, unrecognized, about some farm building, instead of being where it properly belongs—in the State Cabinet. In a State that has been so favored in the number of its meteoric falls, it would seem to be natural that its people should be alert to gather and preserve these interesting objects. Professor Venable has recently shown that the authenticated fall within the State bears a strikingly large ratio to the entire number of all recorded meteoric falls. The recognition and preservation of the earlier North Carolina meteorites is almost exclusively due to the commendable zeal of General Clingman, and now that the intelligent effort of some of her citizens is directed to the subject it may safely be predicted that the list will soon be much extended.

OSCAWANA ON HUDSON, N. Y., August 19, 1891.

TREATMENT OF ZIRCONS IN PREPARING PURE ZIRCONIUM OXYCHLORIDE.

BY F. P. VENABLE.

Linnemann (Sitz. Ber. Kais. Akad. d. Wissens., Vol. II, 1885, translated in London Chemical News, LII, 233 and 240) has published an account of the "Treatment and Qualitative Composition of Zircons." All previous methods of breaking up the zircon and purifying the zirconia have presented numerous difficulties and proved decidedly unsatisfactory.

Having occasion to prepare some of the compounds of zirconium in considerable quantity and of chemical purity I adopted the methods of Linnemann. In the course of my work I have found it advisable to modify the process in several respects, and I make this publication in order that my experience may be available, and perhaps serviceable, to others.

In the first place, I have found the mechanical preparation can be simplified. I have used North Carolina zircons and have found it sufficient to pulverize them roughly in an iron mortar and then grind in an agate mortar until the powder passed through a 100 mesh sieve. The preliminary exposure during ten days to vapor of hydrofluoric acid and the grinding until the powder passed a silk sieve seemed both unnecessary. The fine powder was repeatedly boiled with strong hydrochloric acid and washed with water. Five hundred grams treated in this way lost seventeen grams, the hydrochloric acid thus dissolving 3.40 per cent. of the whole. The fusions were made in nickel crucibles, which are very much cheaper and less attacked than the silver recommended by Linnemann. The loss comes chiefly

in the cracking of the crucibles during the cooling after fusion. The crucibles used measured 10.5 c. m. in diameter by 8 c. m. in height and held a charge of 100 grams zircon, 400 grams sodium hydroxide and 20 grams sodium fluoride. This is one-half the amount of sodium fluoride recommended by Linnemann, but proved sufficient. The sodium fluoride should be dried beforehand. The sodium hydroxide is first thoroughly melted and the fluoride then added. The mass should be brought to a fairly high temperature and then the zircon powder added. A rapid evolution of gas follows the introduction of the powder. The mass should be well stirred by means of a nickel stirrer—a narrow strip of sheet nickel fastened to a glass rod answers the purpose and keeps the hands beyond the reach of hot alkali occasionally thrown out. If the bubbles threaten to rise over the edge temporary removal of the lamp secures their subsidence. The crucible should not be allowed to cool too far, however. Much seems to depend upon carrying through the reaction rapidly at a high temperature. I have at times doubled and even tripled the length of fusion at a lower temperature without securing the thorough breaking up of the zircon secured at a higher temperature. After the first violent boiling a quieter period follows. The end of the reaction is shown by a thickening of the mass and the rising of large bubbles here and there, also sometimes by a fine spitting or spray. In several instances where weights were kept the undissolved or unattacked portion of the zircon powder amounted to less than five per cent.

The melted mass was poured out upon pieces of sheet nickel for cooling. After solidifying enough to handle with tongs it was broken off and plunged in a beaker of cold water. Water was also put in the crucible after it had cooled, to dissolve off the portions adhering to the sides.

The water separates the sodium silicate from sodium

zirconate, leaving the latter undissolved. This is dissolved in dilute hydrochloric acid and evaporated several times to dryness with fresh amounts of acid in order to drive off the hydrofluoric acid. The separation by means of water is far from perfect, some of the zirconate going into solution, though not enough, usually, to make it worth while to attempt to regain it. There is a good deal of silica left with the undissolved portion. This is separated after evaporation to dryness. The dried mass is reached with dilute hydrochloric acid. There is difficulty sometimes in extracting all of the zirconium chloride in this way. Of course the solution contains large quantities of salt, besides other substances. Zirconium hydroxide is precipitated away from these by ammonium hydroxide, and then thoroughly washed in large jars by decantation. The crude zirconium hydroxide is next dissolved in strong hot hydrochloric acid, using as small an amount as possible. This solution is evaporated to dryness and the crude zirconium chloride obtained placed in a large funnel and washed with a mixture of strong hydrochloric acid and four parts of alcohol. This mixture is poured upon the mass in the funnel and allowed slowly to drain through. Some zirconium chloride is dissolved, but can be recovered by evaporation. The mass in the funnel is left white and fairly pure. To complete the purification this mass is taken and repeatedly crystallized from boiling hydrochloric acid until the acid gives no test for iron, which seems the most persistent among the impurities. I have commonly found it well to repeat this crystallization more than twenty times. The pure oxychloride is gotten in well-formed crystals of glistening whiteness. This method of crystallizing from hydrochloric acid, used by Linnemann, is the only satisfactory one for purifying the zirconium chloride. I have tried the precipitation by hydrogen dioxide, as recommended by Bailey, but the consumption of pure dioxide is

very large and a heavy source of expense, and the pentoxide or mixed oxides yielded is not nearly so convenient as the chloride for further working with. The method described above is shorter than the tedious and expensive treatment with hydrochloric acid, alcohol and ether. Judging from an attempt at carrying it out on a small scale, the amount of ether required in purifying the product from a kilo of zircons would be very large indeed.

The modifications in the process have throughout the aim of cheapening and shortening Linnemann's process, and were successful in both directions, at least under the conditions under which I worked.

A qualitative analysis of the different products obtained while thus decomposing the zircon was made under my direction by Mr. John M. Morehead. It differed in several noteworthy particulars from that made by Linnemann. In the first place, the hydrochloric acid used in the preliminary treatment of the zircon powder extracted a large part of the total tin present. Linnemann does not mention tin as occurring in this solution. No lithium was discovered in any of the solutions, nor any bismuth and zinc. The list of elements found by Mr. Morehead is therefore shorter than Linnemann, who reports sixteen. The list found was sodium, potassium, magnesium, calcium, aluminium, iron, lead, tin, uranium, erbium, silicon and zirconium. Undoubtedly a large proportion of these come from foreign matter mixed with the zircons and sifted into the cracks in the crystal, so as not to admit of separation. A number of the rare elements were looked for without finding them. No thorough spectroscopic examination was made, however.

Mr. Morehead also made several quantitative determinations of the iron, silicon and zirconium, resulting as follows:

Per cent. Zirconia 62.82; 62.59; 63.12; 62.80;
Per cent. Silica 34.10; 34.20; 33.52; 34.10;
Per cent. Ferric Oxide 3.29;

or, taking the means,

$$\begin{aligned} Z\,2\,O_2 &= 62.83 \\ Si\,O_2 &= 33.98 \\ Fe_2\,O_3 &= 3.29 \\ \hline & 100.10 \end{aligned}$$

It is not right to calculate the iron as all in the oxidized condition, as much of it comes from the iron mortar and can be easily separated with a magnet.

QUANTITATIVE ANALYSIS OF THE ZIRCON.

BY J. M. MOREHEAD.

In the following analysis it was found most convenient to fuse a portion of the zircon by the Linnemann process, as modified in the preceding article, and from that portion to make the determinations of zirconia and iron. For the silica a second portion was fused with sodium hydroxide, without the use of fluoride. Several other modes of fusion were first tried without satisfactory results.

The method recommended by Classen was tried. One gram of the powdered zircon was fused with five grams each of sodium and potassium carbonate. Heating for one and a half hours with the blast lamp failed to effect thorough fusion. The cooled mass was leached out with water, acidified with hydrochloric acid and filtered away from the unattacked residue. This process was repeated four times, fusing in each case with the same weights of carbonates. It was then found that out of the original gram of zircon .36 gram remained undissolved. This method was abandoned.

The method finally used was to fuse one gram of powdered zircon with ten grams of sodium hydroxide in a nickel crucible, the fusion continuing with an ordinary burner for one-half hour, and then with a blast lamp for twenty minutes. The contents were then poured upon a piece of sheet nickel and cooled. During fusion the mass was occasionally stirred with a nickel stirrer, which must be thoroughly dry. The caustic alkali left on the rod rapidly attracts water on cooling. The cooled mass on the sheet nickel is transferred to a beaker of water and the crucible is rinsed into the same. This was acidified with hydrochloric acid, and in one case only was a residue left. This hydrochloric acid solution was evaporated to dryness and the silica determined in the usual way. Treatment with ammonium fluoride and weighing of the residue not volatilized is essential, as a small amount of zirconia was always found with the silica.

For the iron the solution freed from silica was made up to a known volume, definite portions withdrawn, and the iron determined by titration with a potassium permanganate solution.

In determining the zirconia, measured portions of the solutions were taken, rendered nearly alkaline with sodium carbonate (this is best done in the cold solution); sodium acetate was then added and the whole heated to boiling. After boiling ten minutes the main part of the zirconia will be found precipitated. This is filtered out. The filtrate is acidified with acetic acid, again raised to boiling and boiled for twenty-five minutes with sulphuretted hydrogen bubbling through. The nickel, coming from the crucible, is thus precipitated and is filtered off. The filtrate is acidified with hydrochloric acid and boiled until no further smell of sulphur dioxide is noticed. Then precipitate with ammonium hydroxide, wash thoroughly, dry and ignite. From the weight of this last precipitate must be

subtracted the known weight of iron present. The sum of the weights of the first precipitate from the sodium acetate, and this last, as corrected, give the amount of zirconia.

The analyses were made from several fusions. The results were as follows:

	Silica.	Zirconia.	Ferric Oxide.	Total.
	34.10	62.82		
	34.20	62.59		
	33.52	63.12	3.285	
	34.10	62.80	3.29	
Mean	33.98	62.83	3.29	100.10

RECORDS OF MEETINGS.

FIFTY-NINTH MEETING.

PERSON HALL, January 16, 1891.

1. Reservoir Dams. William Cain.
2. Progress in Chemistry. F. P. Venable.

SIXTIETH MEETING.

PERSON HALL, February 10, 1891.

3. Vegetable Butter. H. L. Miller.
4. The Welsbach Lamp. J. M. Morehead.
5. Multiple Telegraphy. J. W. Gore.
6. Koch's Treatment of Tuberculosis. R. H. Whitehead.

SIXTY-FIRST MEETING.

PERSON HALL, March 10, 1891.

7. A Geological Trip Into Hyde County. B. E. Shaw.
8. Aluminium. J. V. Lewis.
9. Modern Myths. K. P. Battle.

SIXTY-SECOND MEETING.

PERSON HALL, April 21, 1891.

10. The Electric Motor. J. W. Gore.
11. Applications of the Electric Motor. A. H. Patterson.
12. Photography in Natural Colors. F. P. Venable.
13. A Brief Sketch of the Pea-nut Plant. Gaston Battle.

ADDITIONS TO THE EXCHANGE LIST.

ARGENTINE REPUBLIC.

National Department of Agriculture.

AUSTRIA.

BUDAPEST—R. Hungarian Academy of Sciences.
PRAG—Die Gesellschaft, "Lotos."

ENGLAND.

BIRMINGHAM—The Philosophical Society.
BURTON-ON-TRENT—Natural History Society.

FRANCE.

TOULOUSE—La Société des Sciences Physiques.

GERMANY.

ROSTOCK—Verein der Freunde der Naturgeschichte in Mecklenburg.

ITALY.

BOLOGNA—R. Accad. delle Scienza.
BRESCIA—Ateneo di Brescia.
GENOVA—Societa Letture e Conversazioni Scientifiche.
NAPOLI—Societa di Naturalisti.
PAVIA—Bolletino Scientifico, R. Univ. di Pavia.

LUXEMBOURG.

LUXEMBOURG—Verein Luxemburger Naturfreunde.